

Updates of PDFs in the MSTW framework

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I present results on updates on PDFs which are obtained within the general framework which led to the MSTW2008 PDF sets. There are some theory and procedural improvements and a variety of new data sets, including many relevant up-to-date LHC data. A new set of PDFs is very close to being finalised, with no significant changes expected to the preliminary PDFs shown here.

*XXII. International Workshop on Deep-Inelastic Scattering and Related Subjects
28 April - 2 May 2014
Warsaw, Poland*

*Speaker.

I present an update of the parton distribution functions (PDFs) presented by the MSTW collaboration [1]. The overall procedure for obtaining these PDFs is in most ways very similar to this previous analysis. However, there are a number of changes in theoretical treatment or procedures, and a large number of new or updated data sets included, particularly from the LHC.

In the new analysis we continue to use the extended parameterisation with Chebyshev polynomials, and the additional freedom in deuteron nuclear corrections introduced in [2] which led to a change in the $u_V - d_V$ distribution. We now also use the optimal GM-VFNS choice [3] which is smoother near to the heavy flavour transition points, particularly at NLO. We correct the $\nu + N \rightarrow \mu^+ \mu^-$ cross-sections [4] for a missing small contribution, though checks show this has a very small effect on the strange quark distribution. However, also relevant for these data, we have changed the value of the charm branching ratio to muons used, and additionally we now apply an uncertainty on the branching ratio which feeds into the PDFs. Specifically we use $B_\mu = 0.092 \pm 10\%$ from [5], which is not reliant on a PDF input which might bias the result. We update to a more recent determination of nuclear target corrections [6]. These improves the global fit quality by ~ 25 units, mainly in nuclear target structure functions. We now treat correlated systematic errors as being multiplicative not additive. Explicitly we use using the χ^2 definition

$$\chi^2 = \sum_{i=1}^{N_{pts}} \left(\frac{D_i + \sum_{k=1}^{N_{corr}} r_k \sigma_{k,i}^{corr} - T_i}{\sigma_i^{uncorr}} \right)^2 + \sum_{k=1}^{N_{corr}} r_k^2, \quad (1)$$

where $\sigma_{k,i}^{corr} = \beta_{k,i}^{corr} T_i$ and $\beta_{k,i}^{corr}$ are the percentage errors. The additive definition, which previously we used for all but the normalisation uncertainty, would use $\sigma_{k,i}^{corr} = \beta_{k,i}^{corr} D_i$. Effectively if

$$D_i + \sum_{k=1}^{N_{corr}} \beta_{k,i}^{corr} D_i \sim f * D_i \quad \text{or} \quad T_i - \sum_{k=1}^{N_{corr}} \beta_{k,i}^{corr} T_i \sim T_i / f, \quad (2)$$

$$\text{then} \quad \chi^2 \sim \left(\frac{f * D_i - T_i}{\sigma_i^{uncorr}} \right)^2 \quad \text{or} \quad \chi^2 \sim \left(\frac{D_i - T_i / f}{\sigma_i^{uncorr}} \right)^2 = \left(\frac{f * D_i - T_i}{f * \sigma_i^{uncorr}} \right)^2, \quad (3)$$

so with our new choice the uncorrelated errors scale with the data. We make some other additional minor changes, but none have any significant impact.

There are also various changes in non-LHC data sets. Most important is the replacement of HERA run I neutral and charged current data from H1 and ZEUS with the combined data set with the full treatment of correlated errors [7]. The fit to the data is very good and is slightly better at NNLO than at NLO. We include the HERA combined data on $F_2^c(x, Q^2)$ [8]. Again the fit quality is about $\chi^2 = 1$ per point. There is no inclusion of separate run II H1 and ZEUS data sets yet, since we wait instead for the Run II combination data. We include some updated Tevatron data sets, i.e. the CDF W -asymmetry data [9], the D0 electron asymmetry data [10] with $p_T > 25$ GeV based on 0.75 fb^{-1} and new D0 muon asymmetry data [11] for $p_T > 25 \text{ GeV}$ based on 7.3 fb^{-1} . We also include final numbers for CDF Z -rapidity data [12] – preliminary numbers were used in the MSTW2008 fit – though this leads to very little change in PDFs. Overall the inclusion of the new HERA and Tevatron data and the change in procedures results in only a small change in the PDFs, other than already seen in $u_V - d_V$ [2], or in the best fit value of $\alpha_s(M_Z^2)$. At NLO $\alpha_s(M_Z^2) \rightarrow 0.1199$ from 0.1202 and at NNLO $\alpha_s(M_Z^2) \rightarrow 0.1180$ from 0.1171. The central value of the PDFs obtained from these changes are shown at NLO as a ratio to MSTW2008 in Figs. 1 and 2.

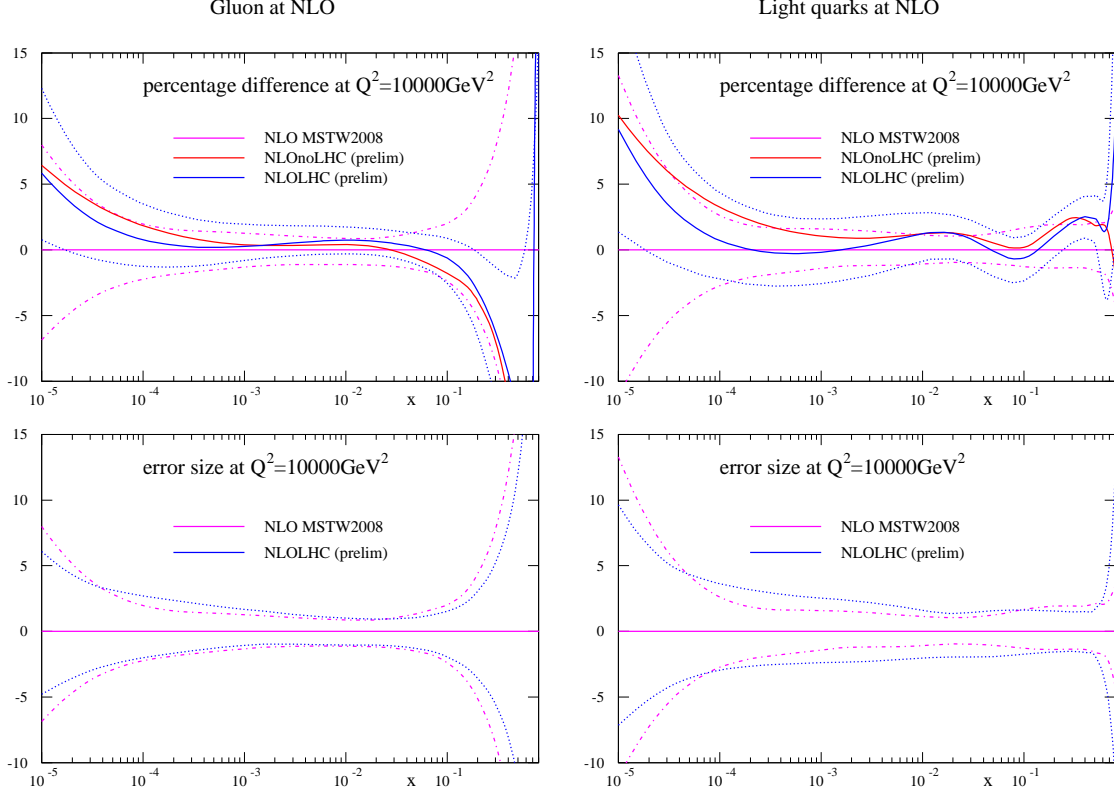


Figure 1: Comparison of the gluon and light quark distribution at NLO.

As well as the updates mentioned above we now include a large variety of LHC data in the fits. A large component of this is rapidity-dependent vector boson production: ATLAS W, Z cross sections differential in rapidity [13]; CMS data on the asymmetry of W bosons decaying to leptons [14, 15], and Z rapidity data [16]; LHCb data on W and Z rapidity distributions [17, 18]; and ATLAS high mass Drell Yan data [19]. (We are yet to finalise fits to the data in [21].) The MSTW2008 data were known to describe the CMS W asymmetry data and implicitly the asymmetry inherent in the ATLAS W data badly, but this was automatically improved enormously by the change in the small x valence quarks in the MSTWCPdeut sets [2]. The W^+/W^- asymmetry is no longer a problem at all for either the ATLAS and CMS data, with predictions and fit good, though slightly better at NLO. The fit quality for the ATLAS W, Z rapidity data before LHC data are included is $\chi^2 \sim 1.6$ per point at NLO and $\chi^2 \sim 2$ per point at NNLO. Inclusion of LHC data in the fit leads to some extra improvement at NLO, $\chi^2 \sim 1.3$, with the strongest pull on the gluon PDF. The quality also improves to $\chi^2 \sim 1.3$ at NNLO, where the most obvious change is in the strange quark. The fit quality to all other vector boson production data is good. We also include data on $\sigma_{t\bar{t}}$ from the combined cross section measurement from D0 and CDF [20], and all published data from ATLAS and CMS, using $m_t^{\text{pole}} = 172.5$ GeV (the value used in the Tevatron combination) with an error of 1 GeV. Predictions and fit results are good, with NLO preferring masses slightly below $m_t = 172.5$ GeV and NNLO masses slightly above.

At NLO we also include CMS inclusive jet data data [21] together with ATLAS 7 TeV[23] and 2.76 TeV data [24]. The ATLAS fit quality is $\chi^2/N_{pts} = 112/114$ and for CMS is $\chi^2/N_{pts} = 186/133$ before the data are included directly – at least as good as most other PDF sets. (This does not include the further breakdown of one correlated uncertainty into five recommended in [25],

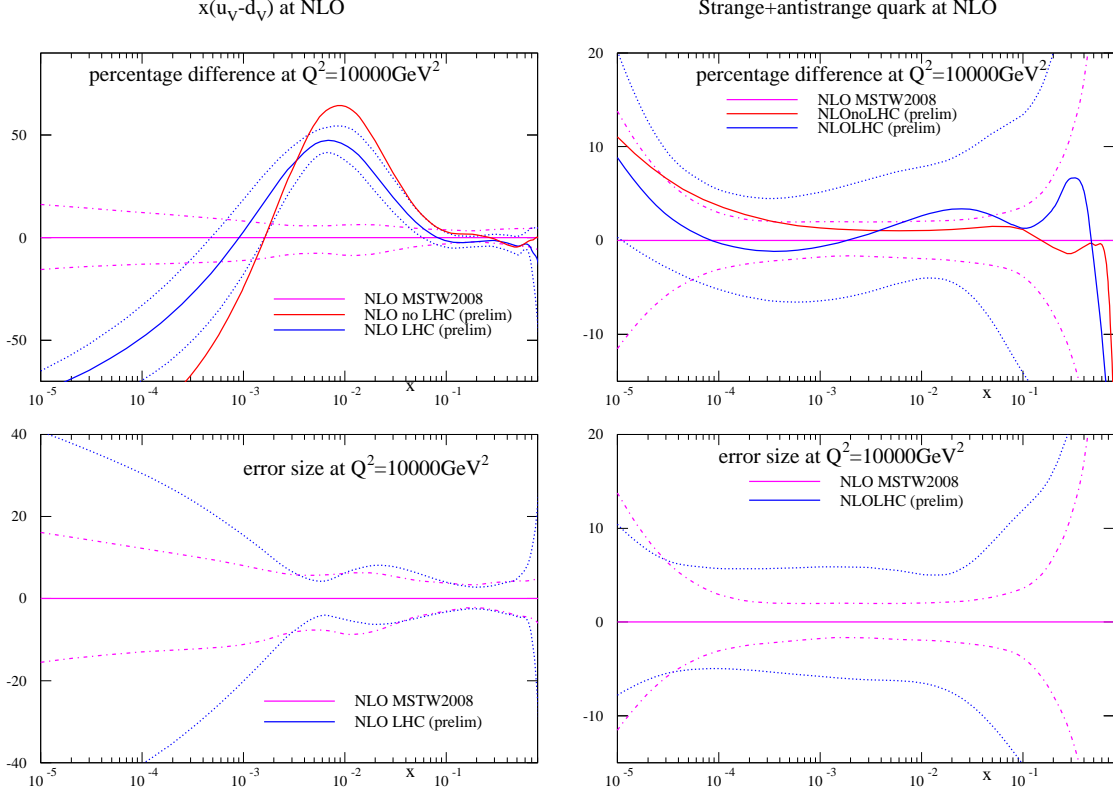


Figure 2: Comparison of the $u_v - d_v$ and $s + \bar{s}$ distribution at NLO.

which lowers the χ^2 to about 1 per point.) The simultaneous fit of CMS data together with ATLAS 7 TeV+ 2.76 TeV data leads to a reasonable improvement for CMS data, but only a tiny amount for ATLAS data. The inclusive jet data from the experiments seem extremely compatible. Including all the LHC data at NLO leads to $\alpha_s(M_Z^2) = 0.1193$, close to the MSTW2008 value. Whether to include inclusive jet data at NNLO is not clear. Previous analyses have used the approximate threshold corrections [26] which give about a 10-20% correction. For LHC data the corrections are very similar for fairly high x values such as those probed at the Tevatron, as illustrated in Fig. 50 of [27], but they blow up when low x is probed at the LHC, i.e. far from threshold. Moreover, the initial threshold calculation does not account for the variation with different jet radius R . A recent improved calculation [28] has built in R dependence and shows that while the R -dependence is large at NLO there is little extra R variation at NNLO. However, the calculations still have problems at low p_T . The enormous project of the full NNLO calculation [29, 30] is nearing completion, and gives some indications of the full form of the correction, with correspondence to the approximate threshold correction in the appropriate region. Hence, as default at NNLO we still fit Tevatron jet data, which seems safe since these are always relatively near to threshold. We do not include the LHC jet data in the standard fit. However we also try putting in “smaller” and “larger” approximate NNLO K -factors for the LHC data, i.e. with corrections of about $\sim 10\%$ and $\sim 20\%$ respectively at $p_T = 100$ GeV. The prediction for LHC data is good for the PDFs where the data are not included in the fit. The fit quality is a small amount worse than at NLO, and deteriorates a little with the larger K -factor. At NNLO the extracted $\alpha_s(M_Z^2) = 0.1162$, but with a larger uncertainty in the upwards direction. When the LHC jet data are included in a fit the quality improves by a few units in χ^2 , mainly for CMS data, and both PDFs and $\alpha_s(M_Z^2)$ change by amounts very much smaller

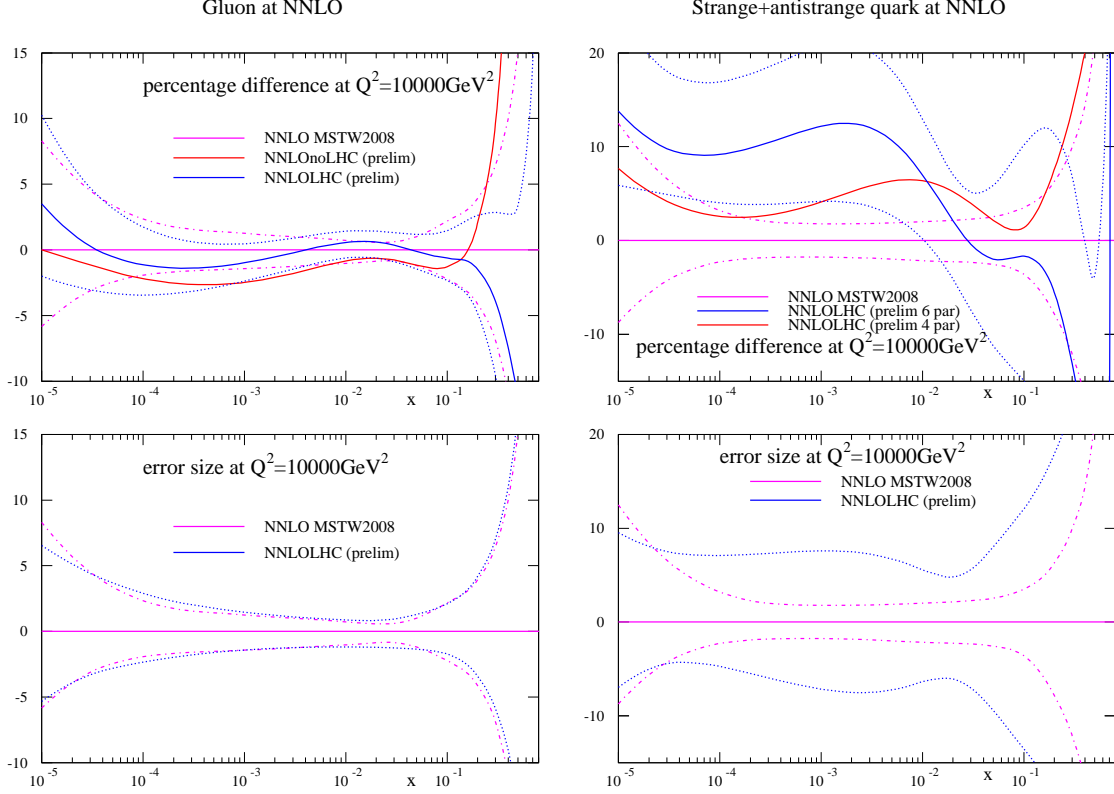


Figure 3: Comparison of the gluon and $s + \bar{s}$ distribution at NNLO.

than their uncertainty. For most of the PDFs the change compared to MSTW2008 at NNLO is very similar to that at NLO. There are some differences for the gluon and strange quark, and the central values obtained in our updated fit are shown at NNLO as a ratio to MSTW2008 in Fig. 3. The uncertainty on the NNLO gluon is perhaps slightly larger at high x due to the omission of LHC jet data. The strange quark increases slightly more at NNLO than it does at NLO, though the details depend on the number of free parameters in the strange quark distribution, where 6 free parameters gives some unusual features, so we reduce to four.

These NLO and NNLO PDFs are not final, but we expect little change in an updated set soon to be released.

Acknowledgements

We would like to thank W. J. Stirling and G. Watt for numerous discussions on PDFs. This work is supported partly by the London Centre for Terauniverse Studies (LCTS), using funding from the European Research Council via the Advanced Investigator Grant 267352. RST would also like to thank the IPPP, Durham, for the award of a Research Associateship. We would like to thank the Science and Technology Facilities Council (STFC) for support.

References

- [1] A. D. Martin, W. J. Stirling, R. S. Thorne and G. Watt, *Eur. Phys. J. C* **63** (2009) 189 [arXiv:0901.0002 [hep-ph]].
- [2] A. D. Martin, A. J. T. .M. Mathijssen, W. J. Stirling, R. S. Thorne, B. J. A. Watt and G. Watt, *Eur. Phys. J. C* **73** (2013) 2318 [arXiv:1211.1215 [hep-ph]].
- [3] R. S. Thorne, *Phys. Rev. D* **86** (2012) 074017 [arXiv:1201.6180 [hep-ph]].

- [4] M. Goncharov *et al.* [NuTeV Collaboration], Phys. Rev. D **64** (2001) 112006 [hep-ex/0102049].
- [5] T. Bolton, hep-ex/9708014.
- [6] D. de Florian, R. Sassot, P. Zurita and M. Stratmann, Phys. Rev. D **85** (2012) 074028 [arXiv:1112.6324 [hep-ph]].
- [7] F. D. Aaron *et al.* [H1 and ZEUS Collaboration], JHEP **1001** (2010) 109 [arXiv:0911.0884 [hep-ex]].
- [8] H. Abramowicz *et al.* [H1 and ZEUS Collaborations], Eur. Phys. J. C **73** (2013) 2311 [arXiv:1211.1182 [hep-ex]].
- [9] T. Aaltonen *et al.* [CDF Collaboration], Phys. Rev. Lett. **102** (2009) 181801 [arXiv:0901.2169 [hep-ex]].
- [10] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. Lett. **101** (2008) 211801 [arXiv:0807.3367 [hep-ex]].
- [11] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. D **88** (2013) 091102 [arXiv:1309.2591 [hep-ex]].
- [12] T. A. Aaltonen *et al.* [CDF Collaboration], Phys. Lett. B **692** (2010) 232 [arXiv:0908.3914 [hep-ex], arXiv:0908.3914 [hep-ex]].
- [13] G. Aad *et al.* [ATLAS Collaboration], Phys. Rev. D **85** (2012) 072004 [arXiv:1109.5141 [hep-ex]].
- [14] S. Chatrchyan *et al.* [CMS Collaboration], JHEP **1104** (2011) 050 [arXiv:1103.3470 [hep-ex]].
- [15] S. Chatrchyan *et al.* [CMS Collaboration], Phys. Rev. Lett. **109** (2012) 111806 [arXiv:1206.2598 [hep-ex]].
- [16] S. Chatrchyan *et al.* [CMS Collaboration], Phys. Rev. D **85** (2012) 032002 [arXiv:1110.4973 [hep-ex]].
- [17] R. Aaij *et al.* [LHCb Collaboration], JHEP **1206** (2012) 058 [arXiv:1204.1620 [hep-ex]].
- [18] R. Aaij *et al.* [LHCb Collaboration], JHEP **1302** (2013) 106 [arXiv:1212.4620 [hep-ex]].
- [19] G. Aad *et al.* [ATLAS Collaboration], Phys. Lett. B **725** (2013) 223 [arXiv:1305.4192 [hep-ex]].
- [20] T. A. Aaltonen *et al.* [CDF and D0 Collaborations], Phys. Rev. D **89** (2014) 072001 [arXiv:1309.7570 [hep-ex]].
- [21] S. Chatrchyan *et al.* [CMS Collaboration], JHEP **1312** (2013) 030 [arXiv:1310.7291 [hep-ex]].
- [22] S. Chatrchyan *et al.* [CMS Collaboration], Phys. Rev. D **87** (2013) 11, 112002 [arXiv:1212.6660 [hep-ex]].
- [23] G. Aad *et al.* [ATLAS Collaboration], Phys. Rev. D **86** (2012) 014022 [arXiv:1112.6297 [hep-ex]].
- [24] G. Aad *et al.* [ATLAS Collaboration], Eur. Phys. J. C **73** (2013) 2509 [arXiv:1304.4739 [hep-ex]].
- [25] CMS Collaboration [CMS Collaboration], “PDF constraints and extraction of the strong coupling constant from the inclusive jet cross section at 7 TeV,” CMS-PAS-SMP-12-028.
- [26] N. Kidonakis and J. F. Owens, Phys. Rev. D **63** (2001) 054019 [hep-ph/0007268].
- [27] B. J. A. Watt, P. Motylinski and R. S. Thorne, arXiv:1311.5703 [hep-ph].
- [28] D. de Florian, P. Hinderer, A. Mukherjee, F. Ringer and W. Vogelsang, Phys. Rev. Lett. **112** (2014) 082001 [arXiv:1310.7192 [hep-ph]].
- [29] A. Gehrmann-De Ridder, T. Gehrmann, E. W. N. Glover and J. Pires, Phys. Rev. Lett. **110** (2013) 16, 162003 [arXiv:1301.7310 [hep-ph]].
- [30] J. Currie, A. Gehrmann-De Ridder, E. W. N. Glover and J. Pires, JHEP **1401** (2014) 110 [arXiv:1310.3993 [hep-ph]].